SECTION 520.00 – THICKNESS DESIGN FOR RIGID PAVEMENT

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The design procedure described herein is based on the 1993 AASHTO GUIDE FOR DESIGN OF PAVEMENT STRUCTURES. Computer software adopted by the department for rigid pavement design is DARWin 2.0 (or later) PAVEMENT DESIGN SYSTEM.

520.01 Summary of Design Factors.

1. Traffic, W_{18} – 18 kip (8000kg) equivalent single axle loads (ESALs).
2. Effective Modulus of subgrade reaction, k.
3. Reliability, R - Reliability design factor.
4. Standard Deviation, S_O.
5. Design Serviceability Loss, $\Delta PSI = p_i - p_t$.
6. Concrete Elastic Modulus, E_c.
7. Concrete Modulus of Rupture, S'_c.
8. Load Transfer Coefficient, J
9. Drainage Coefficient, C_d
10. Thickness of Concrete, D

520.01.01 Traffic Evaluation. Evaluate traffic according to Section 510.02. Use the estimate of accumulated, 18-kip (8000 kg.) ESALs for the design period as input to the design procedure. The design period is normally 40 years. ESALs for rigid pavement design are greatly different then those for flexible pavement design due to the difference in the load carrying mechanisms of the two pavement types. Therefore, exercise caution when extracting these data from the computer printout so that the appropriate loading are used. Observe the directional split and lane distribution shown on the printout.

520.01.02 Subgrade Support. The quality of subgrade support is expressed in terms of the modulus of subgrade reaction (K). Determine “K” according to Section 520.02.01 or by direct measurement according to AASHTO T 222.

Since the effective k-value is dependent upon several different factors besides the roadbed soil resilient modulus, the list of items below, is to identify the combinations that are to be considered.

It is important that subgrade support be uniform. Any improvements to the subgrade should be oriented toward providing uniformity rather than strength.

1. Subbase Types - Different types of subbase have different strengths, or modulus values. The consideration of a subbase type in estimating an effective k-value provides a basis for evaluating its cost-effectiveness as part of the design process.

2. Subbase Thickness - Potential design thickness for each subbase type should also be identified, so that its cost-effectiveness may be considered.

3. Loss of Support – This factor is to account for the potential loss of support arising from subbase erosion and/or differential vertical soil movements. It is treated in the actual design procedure by diminishing the effective or composite k-value based on the size of the void that may develop beneath the slab.

Table 2.7 in the 93 AASHTO Guide for Design of Pavement Structures provides suggested ranges of LS for a variety of materials. For active swelling clays or excessive frost heave, LS values of 2.0 to 3.0 may be appropriate. The values listed below in Table 520.01.1 are suggested values for typical subbase materials.

Table 520.01.1

Type of Material	**Loss of Support (LS)**
Asphalt Treated Base	0 – 0.5
Rock Cap	0.1 – 0.5
3/4" (19 mm) Aggregate Base	0.5 – 1.0

4. Depth to rigid foundation - If bed rock lies within 10 feet (3m) of the surface of the subgrade for any significant length along the project, its effect on the overall k-value and the design slab thickness for that segment should be considered.

For each combination of these factors that is to be evaluated, Section 520.02 Design Procedures covers these factors in developing a corresponding effective modulus of subgrade reaction, K.

520.01.03 Reliability Design Factor (R). The reliability factor accounts for chance variations in both traffic prediction (ESALs) and performance prediction, therefore providing a predetermined level of assurance or reliability (R) that pavement sections will survive their design life. Recommended values for R are listed in Table 520.01.2.

Table 520.01.2

Functional Classification	**Recommended Level of Reliability**
Interstate	90%
Principal Arterial	85%
Minor Arterial	85%
Major Collector	80%

520.01.04 Standard Deviation, (So). Standard deviation accounts for both chance variation in the traffic prediction and normal variation in the pavement performance prediction for a given number of ESALs. A standard deviation value (S_o) of 0.34 should be used for rigid pavement design unless values representative of local conditions can be documented.

It is important to note that by accounting for design uncertainties through the use of reliability and standard deviation. Average values should be used for all other design inputs rather than conservative values.

520.01.05 Design Serviceability Loss ($\Delta PSI = P_o - P_t$). The serviceability of a pavement is defined as its ability to serve the type of traffic, which it facilitates. The primary measure of serviceability is the Present Serviceability Index (PSI), which ranges from 0 (impossible road) to 5 (perfect road). **An index of 2.5 for major highways and 2.0 for highways of lesser traffic volumes be the lowest allowable Terminal Serviceability Index (P_t) tolerated before rehabilitation, or reconstruction becomes necessary.** However, it should be recognized that the Initial Serviceability Index (P_o) values observed at the AASHTO Road Test were 4.5 for rigid pavement, values for ΔPSI are shown in Table 520.01.3.

Table 520.01.3

Design Serviceability Loss	ΔPSI
Interstate and Major Highways	2.0
Secondary Routes, Lower Volume Roads	2.5

520.01.06 Concrete Elastic Modulus, (E_c) and Modulus of Rupture (S'_c). The strength of Portland Cement Concrete (PCC) is expressed in terms of two material properties. The S'_c (Modulus of Rupture) is determined according to AASHTO T 97, Flexural Strength of Concrete (using simple beam with third-point loading). The E_c (Elastic Modulus) is determined according to ASTM C469, Test for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. Tests are performed on 28-day old samples produced and cured according to AASHTO T 123 or AASHTO T 126.

The strength of PCC will vary depending on the aggregate source, mix design, curing conditions and other factors. Use actual test values for S'_c and E_c when available. If not, use the following values for design purposes:

S'_c = 700 psi (4830 kPa), E_c = 4,200,000 psi (29000 MPa).

An S'_c of 700 psi (4830 kPa) is equivalent to a mean concrete compressive strength of 5200 psi (35800 kPa).

520.01.07 Load Transfer Coefficient, (J). Load transfer coefficients, or joint factors (J), are assigned to jointed concrete (with or without dowels) or continuously reinforced concrete pavements, based on the portion of load transferred across the joint or crack. The following values in Table 520.01.4 are assigned to PCC pavement.

Table 520.01.4

Pavement Type	Shoulder	Joint Factor (J)
Continuously Reinforced Concrete	Asphalt	3.2
Continuously Reinforced Concrete	Tied PCC	2.6
Plain Jointed PCC With Dowels	Tied PCC	2.9
Plain Jointed PCC Without Dowels	Tied PCC	4.2

520.01.08 Drainage Coefficient, (C_d). Drainage coefficient is dependent on the quality of drainage and the percent of time during the year the pavement structure would normally be exposed to moisture levels approaching saturation. Below, in Table 520.01.5, are the general definitions corresponding to different drainage levels from the pavement structure:

Table 520.01.5

Quality of Drainage	Water Removed Within
Excellent	2 Hours
Good	1 Day
Fair	1 Week
Poor	1 Month
Very Poor	(Water will not drain)

After obtaining the quality of drainage from the Table above, the drainage coefficient (C_d) for rigid pavement design is provided from Table 520.01.6 as follows:

Table 520.01.6

Recommended Values of Drainage Coefficient, C_d, For Rigid Pavement Design.

Quality of Drainage	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation.			
	Less Than 1%	1 - 5%	5 – 25%	Greater Than 25%
Excellent	1.25-1.20	1.20-1.15	1.15-1.10	1.10
Good	1.20-1.15	1.15-1.10	1.10-1.00	1.00
Fair	1.15-1.00	1.10-1.00	1.00-0.90	0.90
Poor	1.10-1.00	1.00-0.90	0.90-0.80	0.80
Very Poor	1.00-0.90	0.90-0.80	0.80-0.70	0.70

The value of drainage coefficient, C_d, can be obtained from the Table 520.01.6. Recommended values for rigid pavement design are provided from Table 520.01.7 below:

Table 520.01.7

Type of Material	Drainage Coefficient, Cd
Rock Cap	1.20
3/4" (19mm) Aggregate Base	0.50 - 1.00

520.01.09 Thickness, (D). Thickness of PCC pavement is expressed in terms of millimeters (inches) of depth (D). The current AASHTO guide produces the thickness in inches. If the design thickness is to be in metric units, multiply the answer in inches by 25. For uniformity, a standard conversion of 300 mm per foot has been established.

520.02 Design Procedures. Computer software adopted by the department for rigid pavement design is DARWin 2.0 (or later) PAVEMENT DESIGN SYSTEM. Alternatively design inputs can be used in conjunction with Figures 520.02.07.1 through 520.02.07.7 to estimate concrete thickness.

520.02.01 Determine Effective Modulus of Subgrade Reaction. The following procedure describes manual determination of Effective Modulus of Subgrade Reaction. Once the subgrade and subbase moduli are entered, DARWin makes the remaining calculations for each combination of factors mentioned in Section 520.01.02 to be evaluated, it is necessary to prepare a separate table and develop a corresponding effective modulus of subgrade reaction: See Part II Section 3.2.1 of the 1993 AASHTO Guide for Design of Pavement Structures.

1. Identify the seasonal roadbed soil resilient modulus value and enter them in column 2 of each table (Use either two values per month or one value per month). If subgrade support is expressed by the R-value, refer to Figure 520.02.07.7 for the corresponding soil resilient modulus, M_R.

2. Assigned subbase elastic (resilient) modulus (E_{SB}) values for each season are entered into column 3 of Figure 520.02.07.1. If subgrade support is expressed by the R-value, refer to Figure 520.02.07.7 for the corresponding subbase elastic (resilient) modulus, E_{SB}.

3. Estimate the composite modulus of subgrade reaction for each season, assuming a semi-infinite depth (i.e. depth to bedrock greater than 10 feet (3 m)) and enter in column 4. This is accomplished with the aid of Figure 520.02.07.2.

4. Develop a k-value, which includes the effect of a rigid foundation near the surface. This step should be disregarded if the depth to a rigid foundation is greater than 10 feet (3 m). Figure 520.02.07.3 provides the chart that may be used to estimate this modified k-value for each season and should be recorded in column 5 of Figure 520.02.07.1.

5. Estimate the thickness of the slab that will be required, and then use Figure 520.02.07.3 to determine relative damage, u_r, in each season and then enter in column 6 of Figure 520.02.07.1.

6. Add all the u_r in column 6 of Figure 520.02.07.1 and divide by the total number of seasonal increments (12 or 24) to determine the average relative damage, u_r. The effective modulus of subgrade reaction, then, is the value corresponding to the average relative damage (and minimum projected slab thickness) in Figure 520.02.07.4.

7. Adjust the effective modulus of subgrade reaction to account for the potential loss of support arising from subbase erosion. Figure 520.02.07.5 provides the chart for correcting the effective modulus of subgrade reaction based on loss of support factor, LS, determined in Section 520.01.02.

520.02.02 Determine Required Slab Thickness. Manually determine the required pavement slab thickness as follows, using Figure 520.02.07.6 Parts 1 and 2.

1. Using a straightedge, draw a line from the appropriate Effective Modulus of Subgrade Reaction, k to the appropriate Concrete Elastic Modulus, E_c. From E_c draw a line through the appropriate Mean Concrete Modulus of Rupture, S'_c to the turning line 1.
2. From turning line 1 draw a line through the appropriate Load Transfer Coefficient, J to turning line 2.
3. From turning line 2 draw a line through the appropriate Drainage Coefficient, C_d to match line.
4. From the match line on Figure 520.02.07.6 Part 2, draw a line through the appropriate Design Serviceability Loss, ΔPSI to the design slab thickness chart.
5. From the appropriate Reliability, R draw a line through the appropriate Overall Standard Deviation, S_O to turning line 3.
6. From turning line 3 draw a line through the appropriate Estimated Total 10-kip Equivalent Single Axle Load (ESALs) to the design slab thickness chart.
7. From steps 4 and 6 draw lines in the appropriate orientation until they intersect. The intersection of the two lines on the design slab thickness chart will be the required depth of concrete in inches. This value should be rounded up to the next ½ inch in thickness. To convert this value to metric, multiply the depth in inches by 25 to get millimeters. This answer should be recorded to the nearest 10 millimeters.

Figure 520.02.07.1

Table for Estimating Effective Modulus of Subgrade Reaction

Trial Subbase: Type________________ Depth to Rigid Foundation____________
Thickness(in)__________ Projected Slab Thickness (in.)__________
Loss of Support, LS_____

(1) Month	(2) Roadbed Modulus M_R (psi)	(3) Subbase Modulus E_{SB} (psi)	(4) Composite k-Value (pci) Fig. 16-520.2.7.2	(5) k-Value (pci) on Rigid Foundation Fig. 16-520.2.7.3	(6) Relative Damage, u_r Fig. 16-520.2.7.4
Jan					
Feb					
Mar					
Apr					
May					
Jun					
Jul					
Aug					
Sept					
Oct					
Nov					
Dec					
				Summation Σu_r =	

Average: $u_r = \Sigma u_r / n$ = __________

Effective Modulus of Subgrade Reaction, K (pci) = ______________ (Calculated from Ur using Figure 520.02.07.4)

Corrected for Loss of Support: K (pci) = ______________ (From Figure 520.02.07.5)

Figure 520.02.07.2

Example:

D_{SB} = 6 inches

E_{SB} = 20,000 psi

M_R = 7,000 psi

Solution: k_∞ = 400 pci

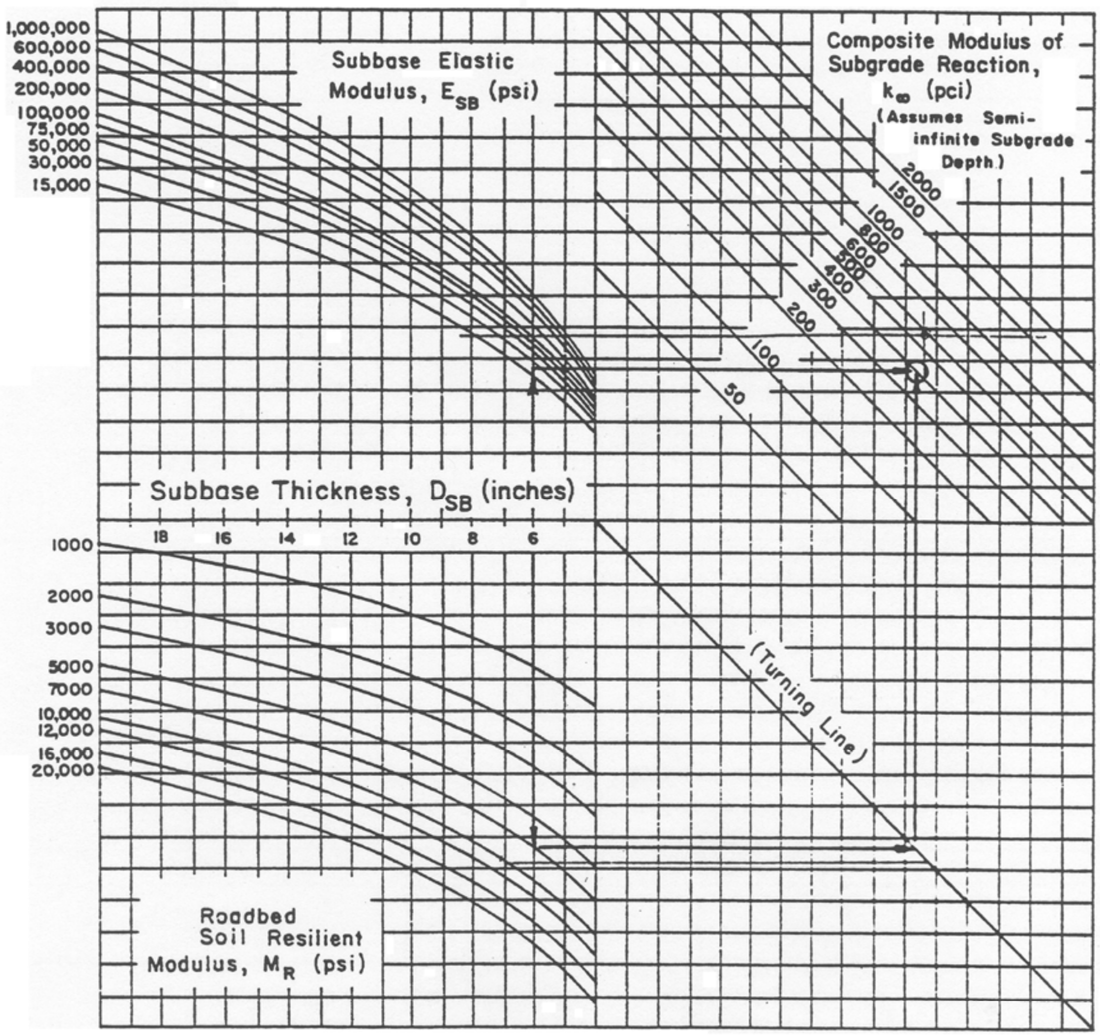
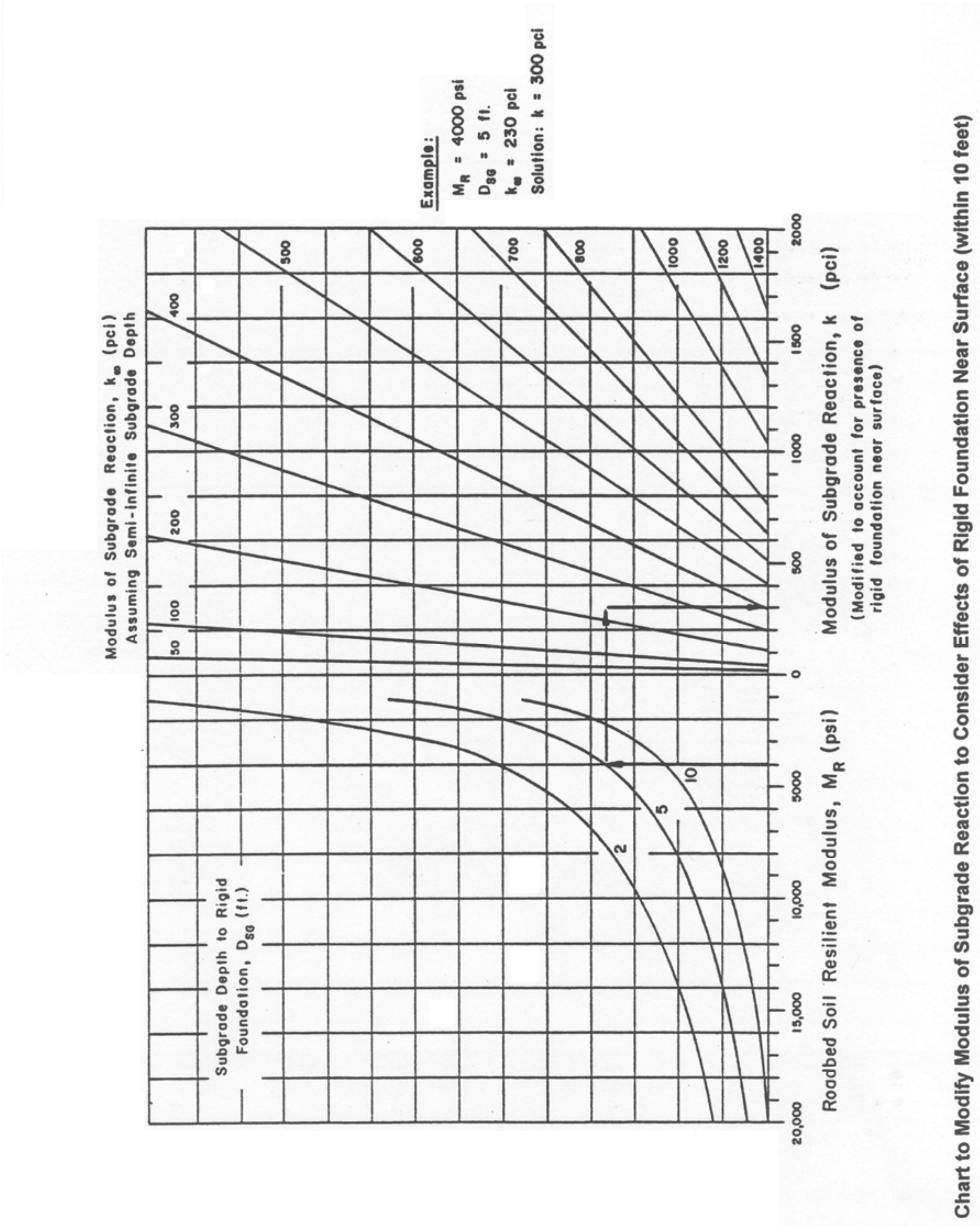


Chart for Estimating Composite Modulus of Subgrade Reaction, k_∞, Assuming a Semi-Infinite Subgrade Depth. (For practical purposes, a semi-infinite depth is considered to be greater than 10 feet below the surface of the subgrade.)

Reference: Part II, Chapter 3, Figure 3.3. AASHTO Guide for Design of Pavement Structures, 1993

Main Menu
Cover
ToC
Memos
100 200
220 240
260 270
400 500
511 520
530 540
542 550
600

Figure 520.02.07.3



Reference: Part II, Chapter 3, Figure 3.4, AASHTO Guide for Design of Pavement Structures, 1993

Figure 520.02.07.4

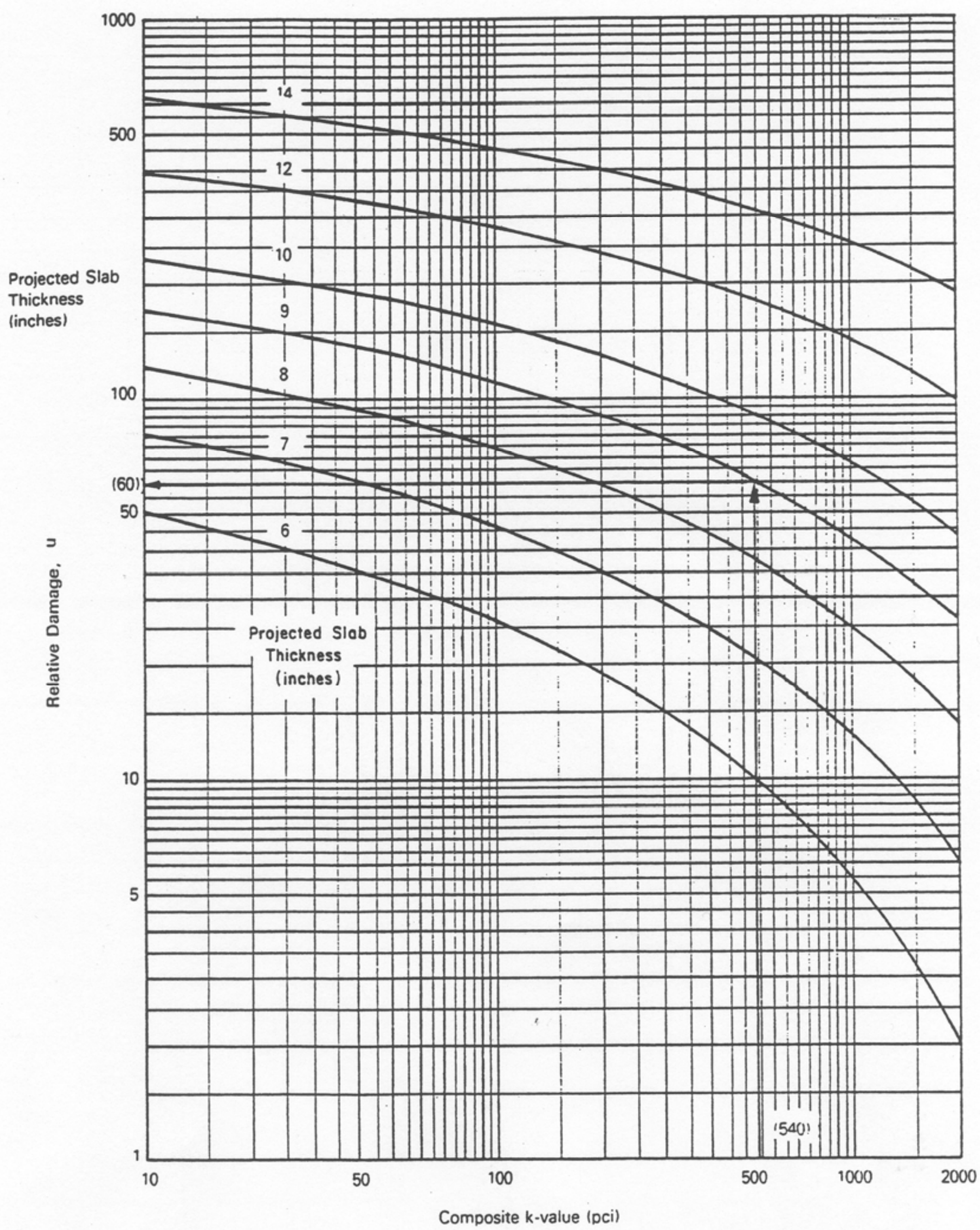
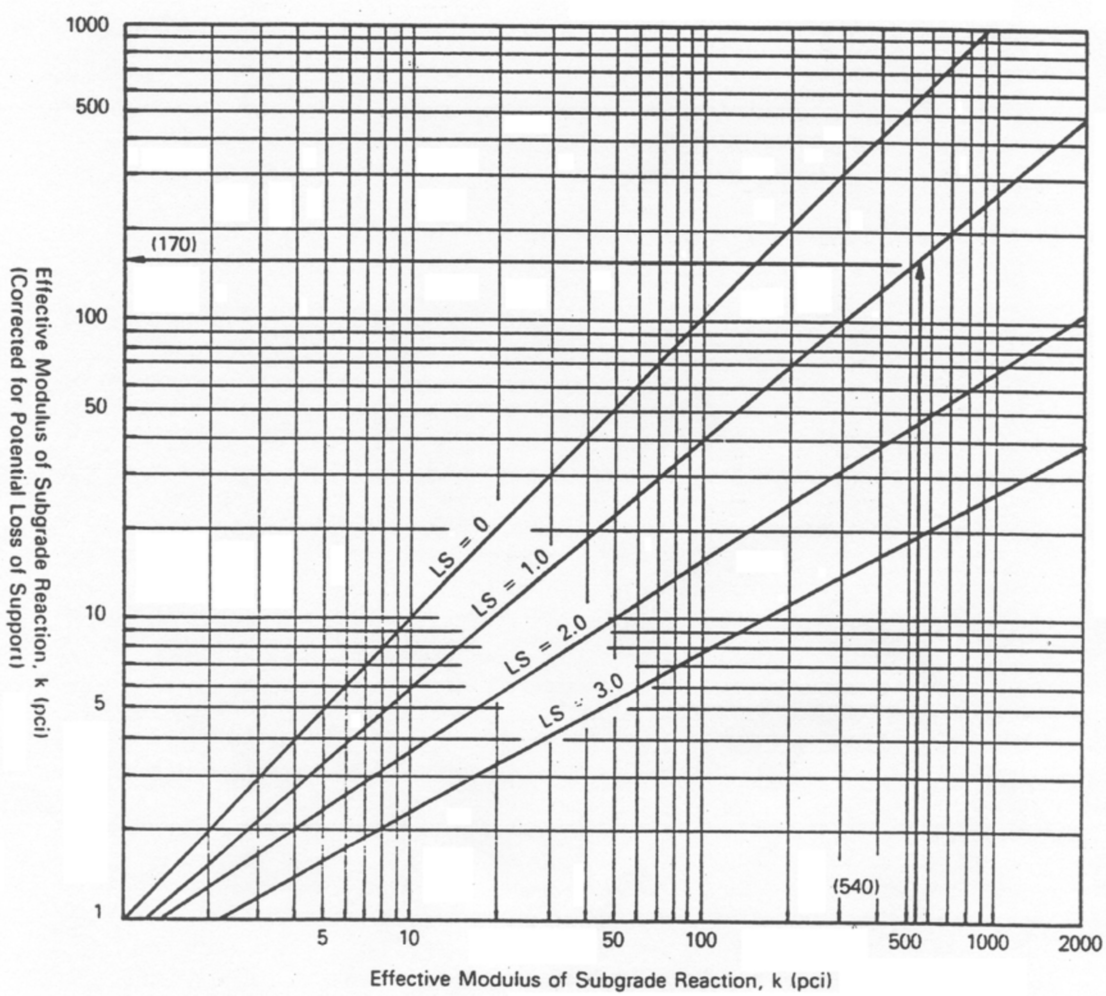


Chart for Estimating Relative Damage to Rigid Pavements Based on Slab Thickness and Underlying Support

Reference: Part II, Chapter 3, Figure 3.6 AASHTO Guide for Design of Pavement Structures, 1993

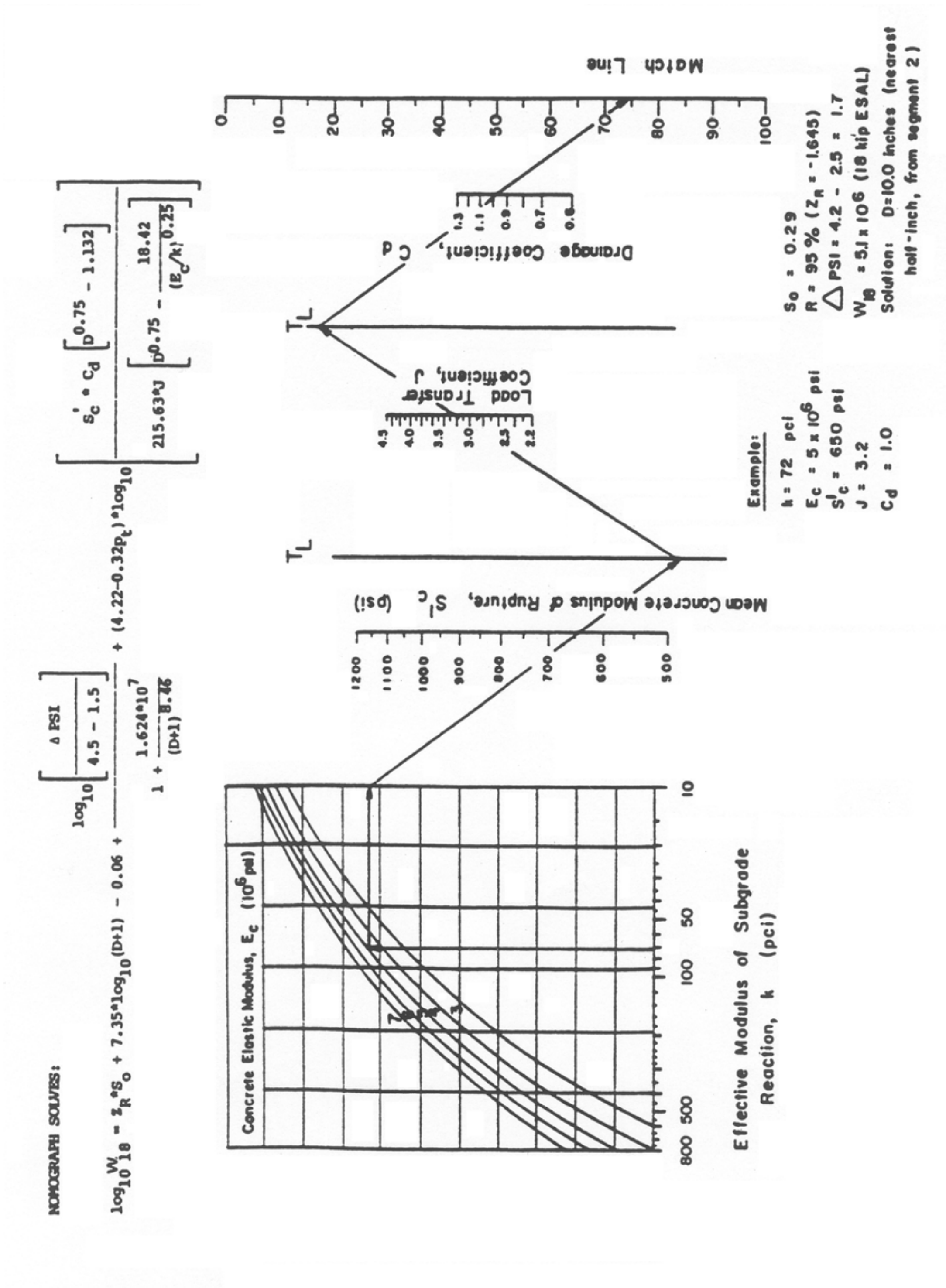
Figure 520.02.07.5



Correction of Effective Modulus of Subgrade Reaction for Potential Loss of Subgrade Support

Reference: Part II, Chapter 3, Figure 3.6, AASHTO Guide for Design of Pavement Structures, 1993

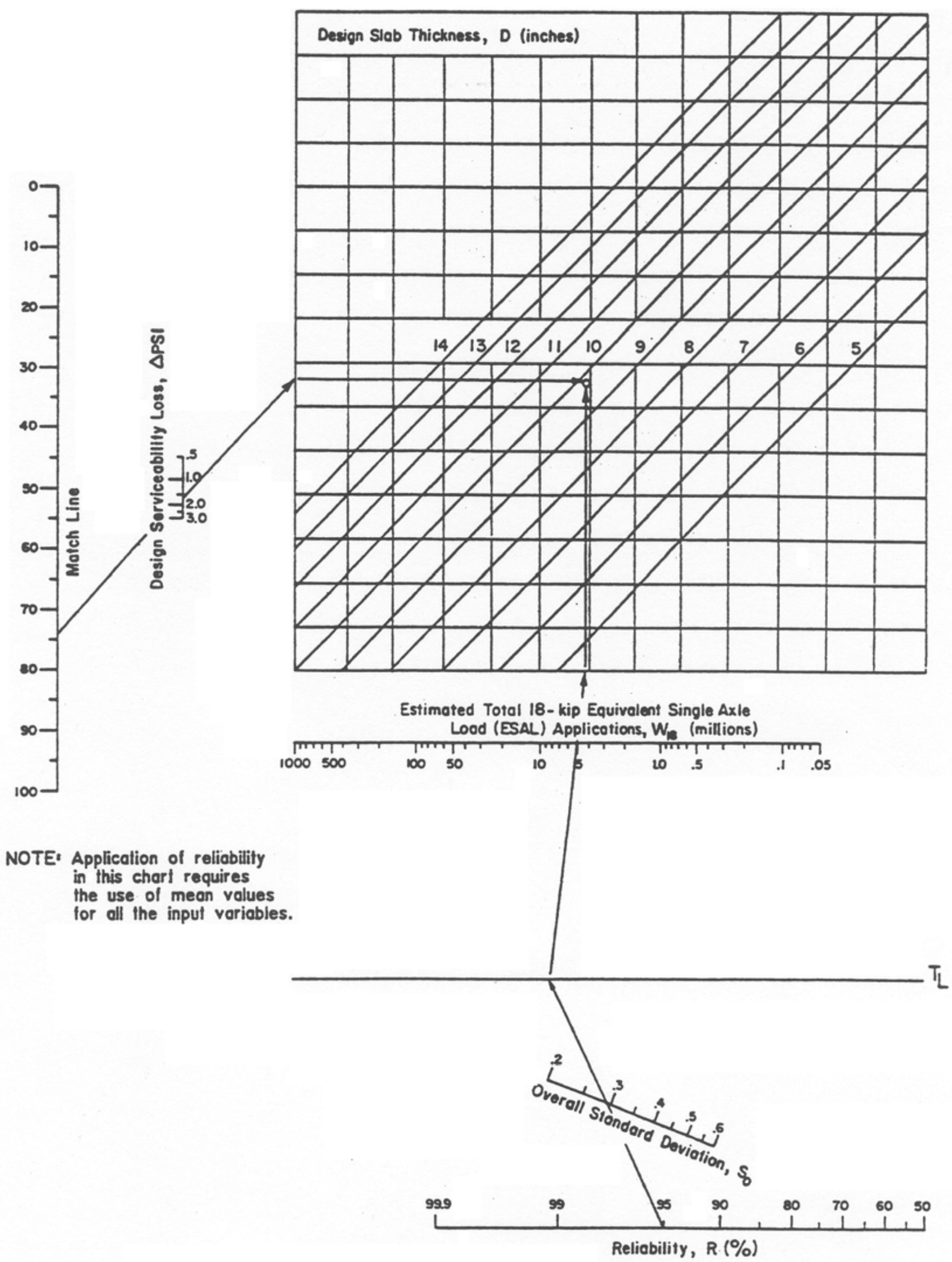
Figure 520.02.07.6 Part 1



Design Chart for Rigid Pavement Based on Using Mean Values for Each Input Variable (Segment 1)

Reference: Part II, Chapter 3, Figure 3.7 Segment 1, AASHTO Guide for Design of Pavement Structures, 1993

Figure 520.02.07.6 Part 2

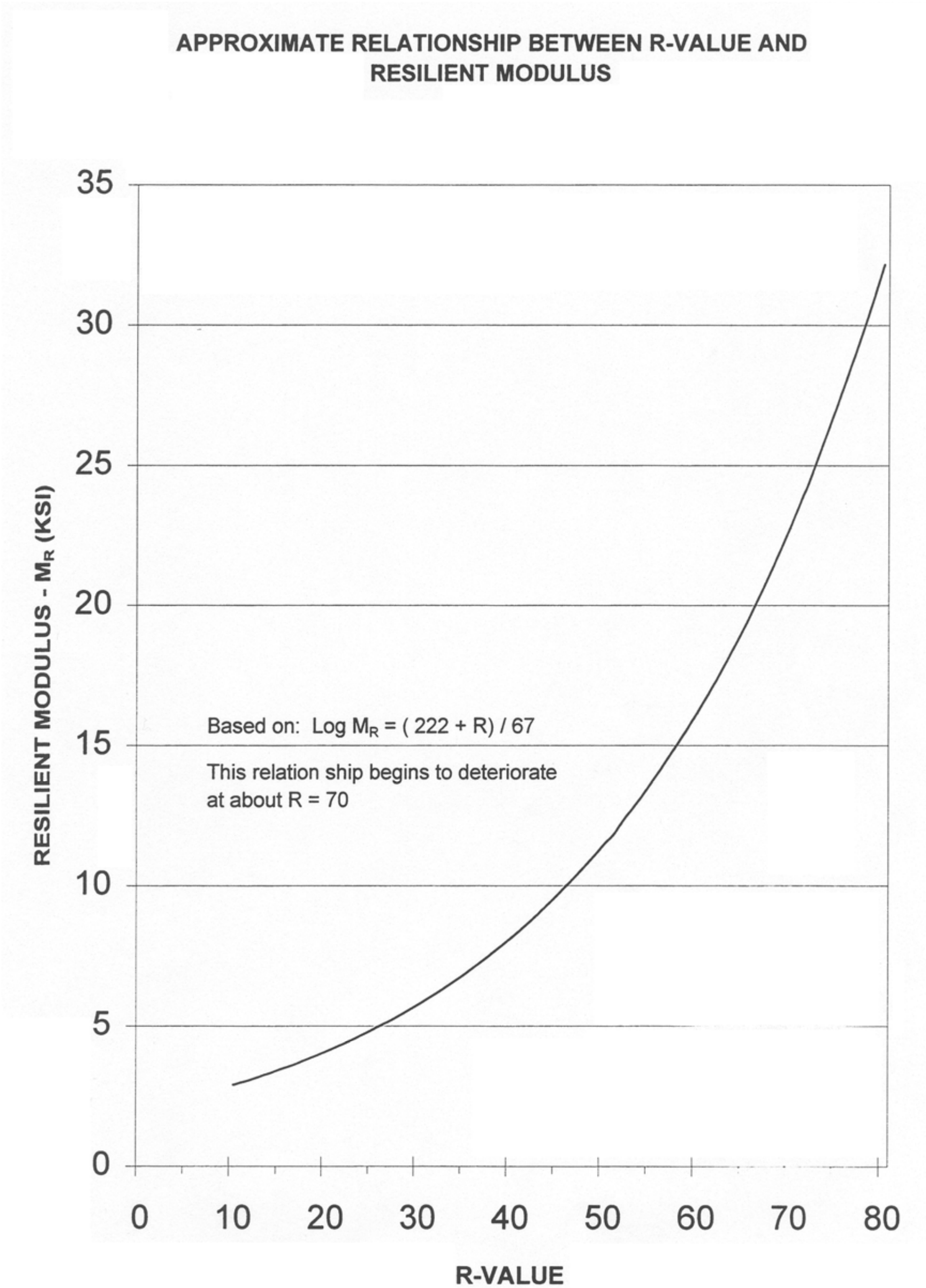


Design Chart for Rigid Pavements Based on Using Mean Values or Each Input Variable (Segment 2)

Reference: Part II, Chapter 3, Figure 3.7 Segment 2, AASHTO Guide for Design of Pavement Structures, 1993

Main Menu
Cover
ToC
Memos
100 200
220 240
260 270
400 500
511 520
530 540
542 550
600

Figure 520.02.07.7



520.02.03 Joint Design. Information on rigid pavement joint design can be found in Part II, Section 3.3 of the 93 AASHTO Guide For Design of Pavement Structures. Joint design details are shown on the following Idaho Transportation Dept., Standard Drawings.

C-1-A(m) and C-1-A: Urban Concrete Pavement Details
C-1-B(m) and C-1-B: Doweled Concrete Pavement Details
C-1-C(m) and C-1-C: Ramp Gore Details

520.02.04 Reinforcement Design. The procedure for rigid pavement reinforcement design can be found in Part II, Section 3.4 of the 93 AASHTO Guide For Design of Pavement Structures. Continuously reinforced and jointed reinforced concrete pavements are rarely constructed in Idaho. Therefore, specific reinforcement design information is not reproduced herein.

520.02.05 Shoulders. For interstate routes, tied concrete shoulders (full width concrete paving) should be used. For rural primary and secondary routes, concrete paving should be carried 2 feet (610 mm) outside the shoulder line if tied shoulders are not specified. For urban paving, monolithic or tied curb and gutter should be used. Each of these treatments will strengthen the pavement edge and reduce shoulder-joint problems.

520.02.06 Minimum Thickness and Reinforcement Requirements. The 12.0 in (300mm) for interstate routes and 9.0 in (230 mm) for all other roadways.

Transverse joints containing dowels or continuous reinforcement are required for roadways with current traffic volumes in excess of 250 commercial vehicles per day.

520.02.07 Design Charts. Design charts for the AASHTO rigid pavement design method are presented on the following pages.